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Properties of the Dead Zone Due to the Gas Cushion Effect in PBX 9502

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Abstract. The dead zone due to precompression by gas trapped between an impactor and PBX 9502 was detected in experiments and its properties measured. The resulting observations are compared to calculations based on published EOS models. Indications are that some reaction is occurring, but very slowly.

INTRODUCTION

It has been known for some time that an explosive can be desensitized when precompressed by gas trapped between an impactor and the explosive [1], the so-called gas cushion effect. Fritz and Kennedy [2] performed a numerical study of this phenomenon and showed that, in such a case, a layer of the explosive is desensitized by ramp compression as the gas is compressed between the impactor and the explosive. Figure 1 shows a calculation of this effect for the insensitive high explosive PBX 9502 (95% TATB and 5% Kel-F 800). While a number of studies of this phenomenon have been performed, none has been specifically aimed at using experimental data to elucidate the properties of this "dead layer." During a series of experiments conducted on PBX 9502, we were able to detect the presence of the dead layer and to obtain data allowing its properties to be estimated. Here, I present comparisons of the properties of the dead layer with those calculated from a model equation of state for the unreacted explosive.

EXPERIMENTS

The typical experimental arrangement is shown in Fig. 2. A sample, with a 100-oriented LiF single crystal window glued to the front surface, is impacted on the rear surface by a flyer plate. A thin aluminum foil is sandwiched between the window and the sample and its velocity history observed using VISAR [3]. Total glue bond thicknesses were typically 1-4 μm. In these experiments, the sample thicknesses were sufficiently small that the shock wave generated by the impact had the opportunity to reflect from the LiF window and then from the sample-impactor interface, reemerging at the sample-window interface prior to arrival of the release from the back of the flyer plate (Fig. 3). Experiments were conducted with the space between the impactor and target filled either with Helium gas or with vacuum. Table 1 gives the experimental parameters.

RESULTS AND ANALYSIS

Figure 4 shows the velocity histories of the foil-window interfaces obtained in the experiments. In the experiments where gas was present between the impactor and sample, an obvious feature precedes the reflection from the impactor, indicating the presence of a thin layer of material having a higher impedance than the explosive products. This feature is absent from experiments conducted with vacuum between the impactor and sample. A short-duration pullback is also noticeable between this feature and the impactor reflection, indicating that the gas

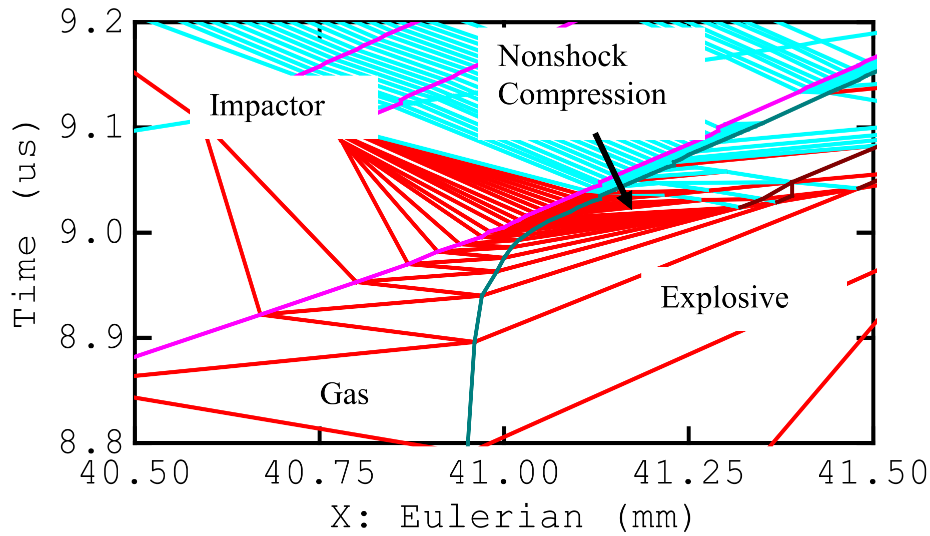

FIGURE 1. Eulerian *x-t* diagram showing the relatively slow compression of a thin layer of material at the impact surface of an explosive impacted by an impactor with intervening gas. In this diagram, red indicates compression, while blue indicates expansion. The presence of expansion waves in this diagram are a result of limitations of the program used to generate the diagram and are not expected to exist in reality.

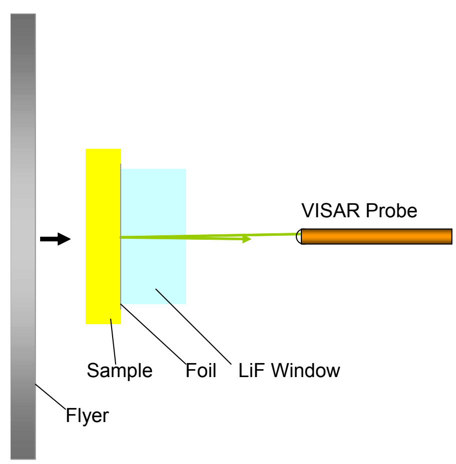

FIGURE 2. Schematic of experiments conducted in this study.

remains as a distinct layer. These features are what would be expected in cases where a layer of the explosive has been desensitized by the ramp compression indicated in Fig. 1.

For comparison to the experiments, impedance matching calculations were performed of the particle velocities expected from the impact and wave reflections. For these calculations, I used the products Hugoniot from the EOS developed by Wescott *et al*. [4] (hereinafter WSD). The precompressed layer was assumed to be isentropically compressed reactants at the same pressure and I used the EOS description from Menikoff [5] for the reactants. Table 2 gives EOS parameters used for the window and impactor materials. The thin Al foils were treated as part of the LiF window in the calculations. Where gas and unreacted explosive were present between the products and impactor, the reflection from the impactor was assumed to asymptotically approach the amplitude be expected in the absence of these intervening layers, so that the direct impedance match between the impactor and the products could still be used to calculate the reflection amplitude. Because of the extended reaction zone apparent in the lower-pressure experiments, no attempt was made to do calculate accurate transit times for the waves in those experiments.

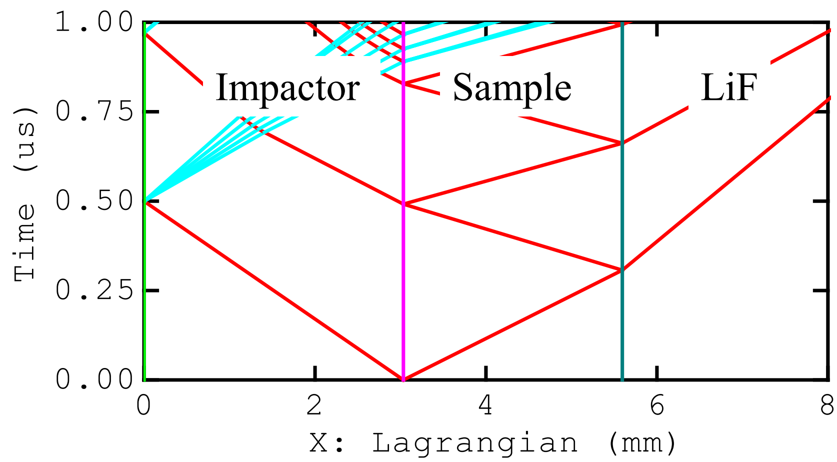

FIGURE 3. Lagrangian *x*-*t* diagram showing wave reflections between LiF window and impactor for a thin sample.

TABLE 1. Experimental Details.

Shot Number	Sample Thickness (mm)	Impactor Material	Impact Velocity (km/s)	Gas Pressure (Pa)	Foil Thickness (mm)
4F-0136	2.561	SS 316	4.219	7.8×10^4 (He)	0.017
4F-0144	2.572	Al 6061	4.167	7.8×10^4 (He)	0.017
4F-AC4834	3.227	Al 6061	3.689	7.8×10^4 (He)	0.008
69-029	2.529	Al 2024	3.682	4 (air)	0.008
69-030	2.532	SS 304	4.109	4 (air)	0.007

TABLE 2. Properties of standard materials used in the calculations.

Material	ρ_0 (kg/m^3)	C_0 (m/s)	s	γ_0[a]	References
SS316	7960	4464	1.544	2.17	6
SS304	7891	4531	1.571	2.2	7,8
Al2024	2785	5328	1.338	1.89	7
Al6061	2703	5288	1.3756	2.14	7
LiF	2640	5215	1.351	1.6	9,10,11,12

[a] $\rho\gamma$ assumed constant.

Figures 5 and 6 compare the measured velocity histories to the calculated velocities. In all experiments, the first shock particle velocities at the sample-window interface are greater than predicted using the WSD products EOS, indicating that the Hugoniot predicted by the WSD EOS parameters is too incompressible. This is consistent with the observation that the WSD products U_s-u_p Hugoniot generally falls above the data, except at low pressures, where the data are extremely scattered. If the amplitude of the calculated first shock arrival is adjusted to match the data, we find that the predicted amplitudes of the reflections from the impactors are generally close to the experimental values, except in shot 69-029, where the experimental reflection has a lower amplitude than predicted.

In experiments with the gas present, the amplitude of the reflection from the dead layer, as a fraction of the reflection from the impactor, is lower than predicted. This can be expected if the dead layer is reacting slowly. In such a case, the layer, which is ~300 µm thick, is immediately adjacent both to the hot compressed gas and the hot reaction products, so that thermally-driven decomposition is probably taking place at some rate. Because the initial shock wave amplitude is not calculated correctly, however, the amplitude of the first reflection from the window cannot be reliably calculated, so that the absolute impedance of both the products and the dead zone cannot be obtained.

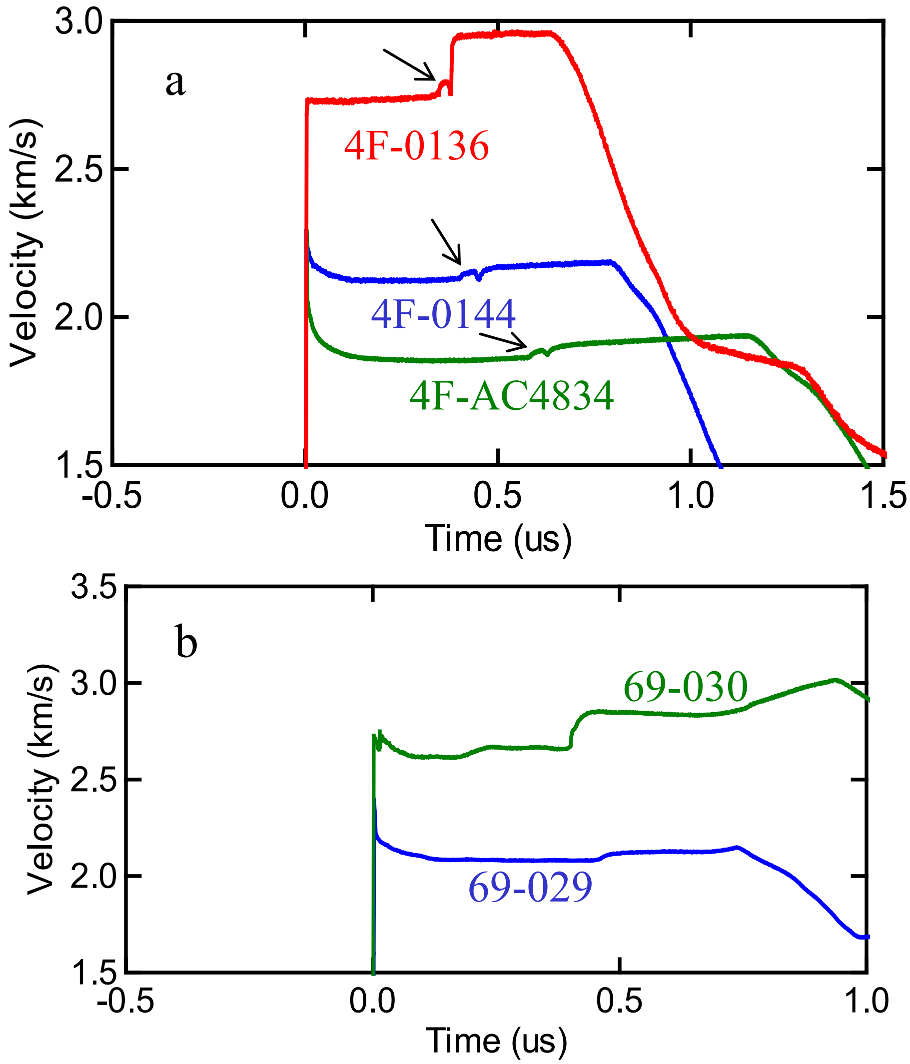

FIGURE 4. Foil-window interface velocity histories for experiments in this study. (a) Experiments with He gas intervening between the impactor and explosive, showing the feature (arrows) interpreted as a wave reflection from a dead layer of explosive. (b) Experiments performed in vacuum, where the feature denoted in (a) is absent.

DISCUSSION AND CONCLUSIONS

The experimental results presented here clearly show that quantitative measurements can be made that provide information on the properties of the dead layer resulting from precompression of an explosive by gas trapped between an impactor and the explosive. In the present case, wave reflections from the dead zone are clearly detectable and their amplitudes can be compared with those of reflections from the impactor. In principle, this should allow the impedance of the dead layer to be determined, but this also requires an accurate EOS for the detonation products. In the present case, it is obvious that the products EOS used is not accurate enough for that purpose. However, we are still able to compare the properties of the dead zone with EOS models for the reactants and assess the possibility of relatively slow reactions occurring in the dead zone. In the present case, the Menikoff model for the reactants seems to provide a good description of the unreacted explosive and allows us to determine that some reaction is occurring. This approach shows promise in obtaining a better understanding of the properties of the dead layer that results from the gas cushion effect.

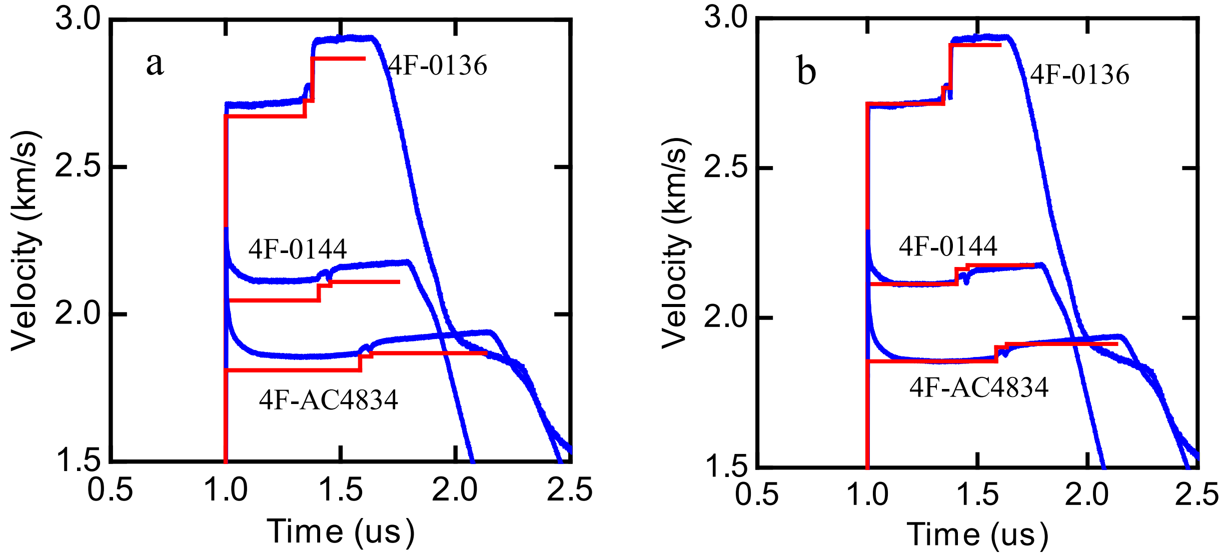

FIGURE 5. Foil-window interface velocity histories in experiments where helium gas was present between the impactor and sample (blue), compared with velocities calculated as described in the text (red). (a) Comparison showing the velocity deficit in the initial plateau velocity, indicating that the products EOS is too compressible on first shock. (b) Comparison with the calculated velocities offset showing the good agreement between the data and calculations for the reflection from the impactor, as well and the relative amplitudes for the reflection from the desensitized layer for calculations using the reactants EOS from Menikoff [4].

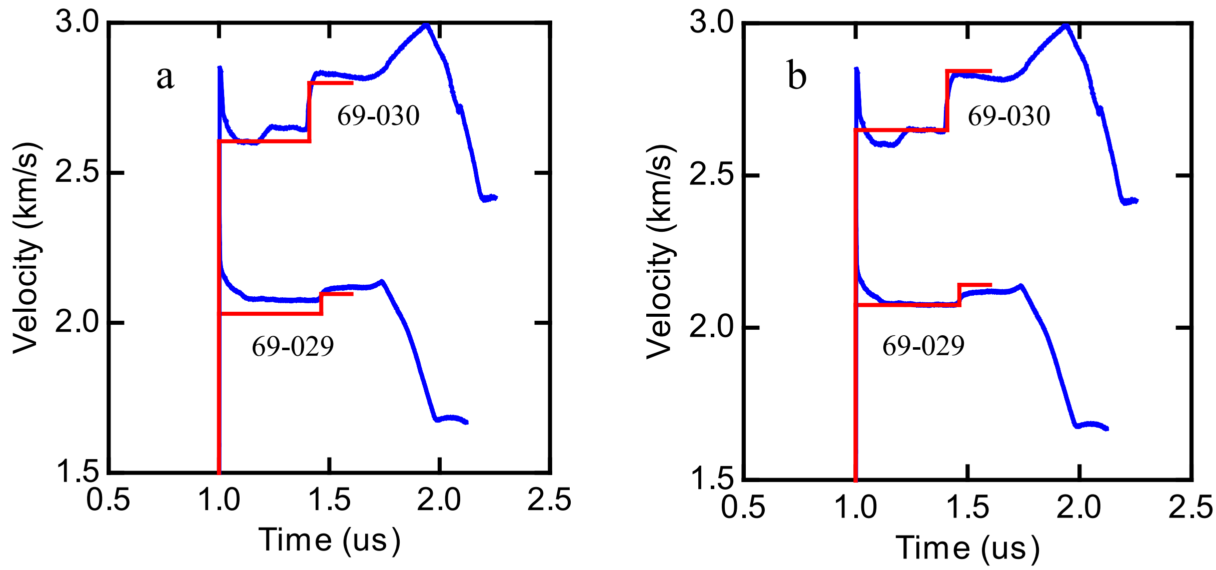

FIGURE 6. Foil-window interface velocity histories in experiments (blue) where the space between the impactor and sample was evacuated, compared with velocities calculated as described in the text (red). (a) Comparison showing the velocity deficit in the initial plateau velocity, indicating that the products EOS is too compressible on first shock. (b) Comparison with the calculated velocities offset showing the good agreement between the data and calculations for the reflection from the impactor.

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